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GAMMA-RAY MEASUREMENTS OF ISOTOPE ACTIVITIES IN VEGETATIVE REFERENCE MATERIALS CLV-1 AND CLV-2

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MICROMEDIA

GAMMA-RAY MEASUREMENTS OF ISOTOPE ACTIVITIES IN VEGETATIVE
REFERENCE MATERIALS CLV-1 AND CLV-2

by

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ABSTRACT

Germanium-detector gamma-ray spectrometry was employed to measure the activities of uranium-238 decay series isotopes and the nuclear-test fallout isotope cesium-137 in CLV-1 and CLV-2. These are respectively spruce twig and spruce needle reference materials collected from Saskatchewan uranium tailings environs. Activities found for CLV-1 were 1.16 ± 0.02 , 0.687 ± 0.006 , 0.690 ± 0.083 , and 0.111 ± 0.004 Bq/g for ^{238}U , ^{226}Ra , ^{210}Pb and ^{137}Cs respectively. For CLV-2 the same isotopes were 0.044 ± 0.005 , 0.039 ± 0.003 , 0.081 ± 0.005 and 0.037 ± 0.003 Bq/g respectively. Uncertainties are 95% confidence interval estimates for the means from quadruplicate measurements. Radon-222 emanation rates of the materials were found to be $73.7 \pm 0.5\%$ for CLV-1 and $30.3 \pm 7.4\%$ for CLV-2.

MESURE PAR RAYONS GAMMA DE L'ACTIVITÉ DES ISOTOPES DANS LES MATÉRIAUX
DE RÉFÉRENCE COMPOSÉS DE VÉGÉTAUX, CLV-1 ET CLV-2

par

C.W. Smith

RÉSUMÉ

La spectrométrie par rayons gamma avec détecteur germanium a été utilisée pour mesurer dans CLV-1 et CLV-2, l'activité des isotopes de la série de résidus d'uranium 238 et de l'isotope césium 137 provenant des retombées radioactives d'un essai nucléaire. CLV-1 et CLV-2 sont des matériaux de référence composés respectivement de brindilles et d'aiguilles d'épinette recueillies dans les alentours d'une décharge de résidus d'uranium en Saskatchewan. Les taux d'activité dans CLV-1 étaient de $1,16 \pm 0,02$, $0,687 \pm 0,006$, $0,690 \pm 0,083$, et de $0,111 \pm 0,004$ Bq/g pour ^{238}U , ^{226}Ra , ^{210}Pb et ^{137}Cs respectivement. Les taux d'activité des mêmes isotopes dans CLV-2 étaient respectivement de $0,044 \pm 0,005$, $0,039 \pm 0,003$, $0,081 \pm 0,005$ et de $0,037 \pm 0,003$ Bq/g. D'après la moyenne d'analyses répétées à quatre reprises, des limites de confiance de l'intervalle de 95 % sont prévues. Les taux d'émanation de radon-222 de CLV-1 et de CLV-2 étaient respectivement de $73,7 \pm 0,5$ et de $30,3 \pm 7,4\%$.

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INTRODUCTION

CLV-1 and CLV-2 are compositional reference materials of spruce tree twigs and needles respectively prepared by the Canadian Certified Reference Materials Project under the auspices of the National Uranium Tailings Research Program. Since the source materials were collected from trees on or near to Canadian uranium tailings sites, they contain measureable quantities of radioactive uranium and associated daughter isotopes in addition to cesium-137 from nuclear test fallout. Once characterized, they consequently will provide organic-matrix isotope-containing reference materials that are relevant to biological aspects of tailings studies.

As a contribution to the interlaboratory certification project conducted in spring 1985, gamma-ray measurements of the activities of uranium-238, radium-226, lead-210, and cesium-137 were made using high-resolution germanium spectrometer facilities at the Mineral Sciences Laboratories, CANMET. Radon-222 emanation rates were also estimated.

EXPERIMENTAL

INSTRUMENTATION

Gamma-ray spectra were acquired using two high-purity germanium spectrometers; a 20 cm² x 2.8 cm true-coaxial configuration having a 0.5 mm thick aluminum end-window, and a 1000 mm² x 5 mm planar configuration having a 0.4 mm Be window. The former was employed for analytical photopeak measurements at energies above 150 keV and the latter was applied for measurements in the range 46-100 keV. The detectors are contained in separate 10 cm-thick lead castles lined with cadmium and copper.

Spectra were acquired with a Canberra Series 85 multichannel analyzer over the ranges 0-2042 keV (0.250 keV/channel) and 0-460 keV (0.114 keV channel). Pulse-shaping time constants of 4 μ s(coaxial) and 8 μ s(planar) were employed. Parameters of the photopeaks that were used for isotope determinations are shown in Table 1.

SAMPLE PREPARATION AND COUNTING

Four samples of each of CLV-1 (71.0 g) and CLV-2 (70.0 g) were compressed uniformly to fill identical 125 mL steel cans (mass thickness about 193 mg/cm²) which were capped and hermetically sealed with instant-bond glue.

Following an equilibration period exceeding 21 d to permit radium-226/radon-222 daughter secular equilibrium to be established, the cans were mounted directly on the detector end windows and the gamma-spectra were acquired typically for 86.4 ks (24 h). For low energy measurements of CLV-2 following the ^{226}Ra measurements, a circular window was cut in the can base and a mylar film installed to improve the sensitivity.

EFFICIENCY CALIBRATION

Photopeak efficiency calibrations (counts/s/Bq) were accomplished with aliquots of isotopic reference materials dispersed on a lithium borate powder matrix prepared in the same geometry and density as the samples. The source materials were Amersham Corp. RBZ.44 (^{210}Pb certified solution) and a solution of Amersham certified radium chloride, RA-31, having total uncertainties of 2.4 and 5.0% respectively. Copies of the certificates are appended. Half-lives of 22.3 y and 1600 y respectively were applied in making decay corrections to the time of measurement. Volumetric aliquots were pipetted onto tared quantities of borate powder, the powder subsequently was dried in a microwave oven, and milled and bleaded to produce homogeneous stock powders. Portions were then tumble-blended with more powder to produce diluted calibration standards. CCRMP uranium/radium-226/lead-210 certified ores BL-4a and BL-5 were also used as calibration sources (1-4). One and two gram quantities were fused in lithium tetraborate and the resultant glass bead was subsequently ground to a powder and blended with more borate powder to produce diluted calibration standards. Activities of ^{238}U , ^{226}Ra and ^{210}Pb in the ore standards were calculated from the uranium values and the constant 123.46 Bq of ^{238}U and secular equilibrium daughters/per cent uranium (5).

Calibration data are presented in Tables 2 and 3. Since the efficiencies measured with the various calibration sources were identical within the expected variations due to counting statistics, the precise efficiency values were determined as the weighted means, using $(1/\sigma^2)$ weighting factors (6).

Efficiency calibration for cesium-137 was performed indirectly from the measured lead-214 and bismuth-214 photopeak efficiencies and application of a power series energy/efficiency relationship (7). Published values of gamma yields (gamma-rays emitted at energy, E, per Bq) were used (8). Results of this calibration are compiled in Table 4.

ACTIVITY CALCULATIONS

The activity of an isotope giving rise to the measured photopeak is calculated as

$$A = R'F/\epsilon W$$

where A is the activity (Bq/g), R' is the net photopeak count rate (s^{-1}), F is an experimentally determined factor correcting for self-absorption differences between the sample and calibration standard matrices, ϵ is the calibration efficiency (counts s^{-1} Bq $^{-1}$), and W is the sample mass (g).

The precision of the determined value of A is estimated as

$$\sigma_A = A[(\sigma_{R'}/R')^2 + (\sigma_{\epsilon}/\epsilon)^2]^{1/2}$$

where $\sigma_{R'}$ and σ_{ϵ} are the precision estimates for R' and ϵ propagated from the counting statistics of their components.

The net photopeak count rate is

$$R' = R - B_C - B_B$$

where R is the integral count rate beneath the photopeak, B_C is the Compton background contribution (determined by linear extrapolation from measurements to the high and low energy sides), and B_B is the photopeak contribution due to the presence of the analyte isotope in the ambient materials of the detector/castle assembly. Observed values of B_B and corresponding detection limit estimates are recorded in Table 5.

The precision of R' is estimated as

$$\sigma_{R'} = [(\sigma_R)^2 + (\sigma_{B_C})^2 + (\sigma_{B_B})^2]^{1/2}$$

where:

$$\sigma_R = N/t,$$

N being the integral counts and t the count period;

$$\sigma B_c = k \sqrt{N_b}/t,$$

N_b being the total counts in the background measurement channels and k the ratio of photopeak channels to background channels; and σB_p being estimated from the standard deviation of repeated photopeak measurements in the presence of blank samples.

The attenuation-difference factors, F , were determined using ^{210}Pb and $^{154}\text{Eu}/^{155}\text{Eu}$ "point" sources with samples and standards as absorbers (9, 10); values at 63 and 93 keV being obtained by interpolation. Results are summarized in Table 6. Attenuation differences above 150 keV were deemed to be negligible.

Where activity values for a given isotope were obtained from several (n) different photopeaks (1) the reported value is the precision-weighted mean (6);

$$\bar{A} = \sum_{i=1}^n (w_i A_i) / \sum_{i=1}^n w_i,$$

where the weighting factors w_i are given by

$$w_i = 1/(\sigma A_i)^2,$$

and

$$\sigma \bar{A} = 1/(\sum_{i=1}^n w_i)^{1/2}.$$

Values for radium -226 (295, 352, 609 and 1120 keV photopeaks), and uranium -238 (63 and 93 keV photopeaks) were obtained in this manner.

RADON-222 EMANATION EFFICIENCY MEASUREMENTS

Radon-222 emanation efficiencies of CLV-1 and CLV-2 were measured as

$$\%E = 100. [1 - A(^{222}\text{Rn})/A(^{226}\text{Ra})]$$

where $A(^{222}\text{Rn})$ is the activity of radon-222 in the sample measured in an open can (as lead-214 and bismuth-214 in secular equilibrium), and $A(^{226}\text{Ra})$ is the activity under conditions of radium-226/radon/radon daughter secular equilibrium i.e., in a can sealed for 30 d or more.

DISCUSSION OF RESULTS

The values obtained for the activities of ^{238}U , ^{226}Ra , ^{210}Pb and ^{137}Cs are reported in Table 7. The activities of all isotopes are higher in the twig specimen CLV-1 compared to the needle specimen CLV-2, the factors ranging from 26 for uranium to 3 for ^{137}Cs . Activities decrease in the order $^{238}\text{U} > ^{226}\text{Ra} \sim ^{210}\text{Pb} > ^{137}\text{Cs}$ in CLV-1, however the order in CLV-2 is $^{210}\text{Pb} > ^{238}\text{U} \sim ^{226}\text{Ra} \sim ^{137}\text{Cs}$ in CLV-2.

The standard deviations of replicate determinations are comparable to propagated 1 σ estimates of the uncertainties with the exception of ^{226}Ra in CLV-1, where the S.D. is considerably larger, i.e., 0.028 vs $\bar{\sigma} = 0.006$. It is suspected that the low result for the third replicate is due to an imperfect can seal resulting in ^{222}Rn leakage yielding a $^{214}\text{Pb}/^{226}\text{Ra}$ activity ratio of less than unity. This result was rejected from calculation of the recommended value.

Results of ^{222}Rn emanation fraction measurements are recorded in Table 8. Both powders are quite porous to radon in contrast to mineralogical ore powders (11). The radon fraction escaping from CLV-2 is less than half of that escaping from CLV-1, for unknown reasons probably related to physical and/or chemical structural differences between the twig and needle powders. Table 9 shows the expected decay of ^{210}Pb activity in CLV-1 and CLV-2 assuming that the measured emanation rates (for materials from partly filled bottles) persist.

The gamma-ray spectra of CLV-1, CLV-2, and the ambient background in the range 20 - 2042 keV obtained with the coaxial spectrometer are shown in Figure 1-3. The spectra are presented with a logarithmic count scale so that the weaker-intensity higher-energy photopeaks become apparent. All gamma-ray lines arising from the samples are identifiable with ^{238}U -series and ^{235}U -series isotopes, ^{40}K and ^{137}Cs (12). Thorium-232 series isotopes are also apparent, but arise from the ambient background within measurement uncertainties. The photopeaks employed analytically (295, 352, 609, 662, and 1120 keV) are indicated by asterisks.

Low-energy spectra of CLV-1 (sealed can) and CLV-2 (through mylar window) from the planar spectrometer are shown in Fig. 4 and 5. Photopeak regions of interest are depicted by doubled points in the expanded scale, and

are seen to be free from spectral interferences. The peak assignments are after Ostrihansky (13). The spectra include background photopeak contribution (Table 5), which amount to 1 - 2% for CLV-1 and 10 - 20% for CLV-2 lead-210 and thorium-234 photopeaks, respectively.

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Table 1 - Characteristics and measurement parameters of photopeaks employed of the measurement of isotope activities

Detector	Planar				Coaxial			
	210Pb	238U	234Th	238U	226Ra	226Ra	226Ra	137Cs
Analyte	210Pb	238U	234Th	234Th	214Pb	214Bi	214Bi	137Cs
Gamma source	46.5	63.4	93.0	93.0	352.0	609.3	1120.0	661.5
Centroid (keV)	0.64	0.69	0.91	0.91	1.0	1.2	1.6	1.3
FWHM ¹ (keV)	2.02	1.80	2.03	2.03	3.50	4.0	4.50	3.30
Interval ² (keV)								

1. Full width at half-maximum intensity.

2. Range of photopeak area measurement. Compton background is interpolated from background measurements over 0.562 keV (planar) and 1.25 keV (coaxial) intervals immediately adjacent to the high-and-low energy sides of the photopeak interval.

Table 2 - Photopeak efficiency calibrations, planar germanium spectrometer. Seventy gram lithium borate powder matrix, 86.4 Ks live-time.

Source	Activity Bq	Activity pCi/g	Net peak efficiency (=2 σ %, Err %) ¹ 10 ⁴ counts/s/Bq					
			Mylar window			Sealed can		
			Isot.: keV:	210Pb	234Th	234Th	210Pb	234Th
BL-4a	1.52	0.59		15.4 (38., 18.)	13.6 (63., 11.)	13.9 (52., 1.5)		
BL-4a	3.03	1.17		12.2 (29., -6.5)	13.9 (30., 13.)	14.4 (29., 5.1)		
BL-4a	6.07	2.34		13.3 (17., 1.9)	15.0 (18., 22.)	15.0 (16., 9.5)		
BL-4a	12.1	4.67		13.8 (10., 5.7)	13.1 (13., 6.5)	15.0 (10., 9.5)	7.63 (18., -5.5)	11.6 (14., 11.) 13.9 (11., 6.8)
RBZ-4a	18.9	7.30		12.9 (6.1, -1.1)			8.43 (9.5, 4.4)	
RBZ-4a	37.7	14.6		12.9 (3.8, -1.1)			7.93 (5.2, -1.8)	
BL-5	66.6	25.7					8.21 (5.8, 1.6)	10.8 (5.3, 3.6) 13.2 (3.9, 1.4)
RBZ-4a	75.5	29.2	13.4 (2.5, 2.7)				8.15 (3.3, 0.9)	
BL-5	133.	51.4	12.7 (2.9, -2.7)	12.2 (3.3, 0.)	13.6 (2.6 0.)		8.06 (3.9, 0.)	10.3 (3.7, -1.1) 12.9 (2.7, -0.9)
BL-5	266.	102.7					8.03 (2.9, -0.6)	10.3 (2.6, -1.1) 13.0 (1.9, -0.2)
wtd mean ² :			13.05	12.3	13.7	8.08	10.42	13.02
2 σ %:			1.60	3.12	2.48	1.70	2.00	1.44

1. 2 σ % is the relative uncertainty propagated from counting statistics;

err% is the error found for the activity when the standard is treated as an unknown and the mean efficiency is employed.

2. Precision-weighted mean and its relative 2 σ uncertainty.

Table 3 - Photopeak efficiency calibrations, coaxial germanium spectrometer,
70 g samples counted for 86.4 ks.

Source	Activity Bq	pCi/g.	Net peak efficiency ($\pm 2\sigma$, Err %)*			
			10^4 counts/s/Bq			
			^{214}Pb	^{214}Pb	^{214}Bi	^{214}Bi
		Isot.:	295.4	352.0	609.3	1120.0
		keV:				
BL-4a	1.52	0.59	48.0 (26., 12.)	70.0 (20., 2.2)	43.0 (18., 2.4)	8.2 (63., 12.)
BL-4a	3.03	1.17	53.0 (14., 23.)	76.0 (11., 11.)	52.0 (9.1, 24.)	9.2 (33., 26.)
BL-4a	6.07	2.34	46.2 (8.1, 7.5)	71.0 (6.1, 3.7)	44.2 (5.9, 5.2)	9.3 (16., 27.)
BL-4a	12.1	4.67	42.9 (4.8, -0.2)	70.7 (3.7, 3.2)	42.8 (3.8, 1.9)	7.4 (12., 1.0)
RA-1	24.0	9.27	44.5 (3.0, 3.5)	70.1 (2.3, 2.0)	42.4 (2.4, 0.9)	7.7 (7.3, 5.0)
BL-5	66.6	25.7	42.8 (1.7, -0.4)	68.9 (1.2, 0.6)	41.6 (1.4, -1.0)	7.33 (4.1, 0.0)
RA-1	120.	46.3	42.5 (1.3, -1.1)	67.0 (1.0, -2.2)	42.0 (1.1, 0.0)	7.32 (2.7, -0.1)
BL-5	133.	51.4	43.1 (1.1, +0.2)	68.8 (0.8, 0.5)	41.7 (1.0, -0.7)	7.36 (2.4, 0.4)
RA-1	240.	92.7	43.0 (0.9, 0.0)	68.6 (0.7, 0.7)	42.2 (0.8, 0.5)	7.24 (2.4, -1.2)
wtd mean*			42.98	68.49	42.01	7.33
2σ			0.65	0.49	0.57	1.64

* See footnotes, Table 2.

Table 4 - Efficiency calibration of coaxial detector for ^{137}Cs measurement, sealed can geometry, 70 g/125 mL. Regression fit of $\epsilon_p = a(\text{MeV})^b$ yields $a = 0.004918$, $b = 1.2642$, correl. coef. = 0.9987.

Isotope	MeV	ϵ , cps/Bq ¹	ϵ_γ , $\gamma \cdot \text{s}^{-1}/\text{Bq}^2$	ϵ_p , cps/ $\gamma \cdot \text{s}^{-1}$ ³	ϵ_p (regression fit)
^{214}Pb	0.2954	4.298×10^{-3}	0.19	0.02262	0.02298
^{214}Pb	0.3520	6.849×10^{-3}	0.36	0.01903	0.01841
^{214}Bi	0.6093	4.201×10^{-3}	0.47	0.00894	0.00920
^{214}Bi	1.120	0.733×10^{-3}	0.17	0.00431	0.00426
^{137}Cs	0.6615	$(7.05 \times 10^{-3})^4$	0.85		0.00829

1. Observed mean efficiencies, Table 2.

2. Tabulated values, reference 8

3. $\epsilon_p = \epsilon/\epsilon_\gamma$

4. Derived efficiency for 661.4 keV photopeak of ^{137}Cs for the experimental geometry.

Table 5 - Ambient background photopeak count rates and "detection limit/" estimates.

Detection limits are estimated (99% confidence level) as $3.6 \sigma_{Rb}/\epsilon$ where σ_{Rb} is the reproducibility of the background photopeak count rate (estimated from the standard deviation of replicate measurements) and ϵ is the detector efficiency, cps/Bq, from Tables 2 and 3. The detection limits are for 24 h measurements of 70 g samples.

Isotope	keV	$Rb \pm \sigma, 10^3 \text{ cps}$		Detection Limit (Bq/g)		
		Coaxial	Planar	Planar (mylar wind.)	Planar (can)	Coaxial (can)
^{210}Pb	46.5	2.4 ± 0.9	1.0 ± 0.2	0.0079	0.013	0.081
^{234}Th	63.5	2.4 ± 0.7	1.0 ± 0.3	0.013	0.015	0.016
^{234}Th	93.0	5.6 ± 0.9	2.1 ± 0.4	0.015	0.016	0.020
^{214}Pb	295.4	0.0 ± 0.7	0.4 ± 0.3		0.019	0.0084
^{214}Pb	352.0	1.8 ± 0.7	0.3 ± 0.3		0.013	0.0053
^{214}Bi	609.3	0.9 ± 0.4				0.0049
^{214}Bi	1120.	0.35 ± 0.3				0.021
^{137}Cs	661.5	0.5 ± 0.4				0.0029

Table 6 - Relative attenuation factors, $F = G_{\text{std}}/G_{\text{sample}}$, where
 $G = [R^*/R_0 - 1]/\ln(R^*/R_0)$, and R^* and R_0 are the photopeak
 count rates in the presence and absence of the absorbing matrix (9).
 The standard matrix is 70 g $\text{Li}_2\text{B}_4\text{O}_7/125 \mu\text{l}$.

Matrix	keV	F					
		(±2σ)					
Source	42.7	46.5	63.5	87.	93.0	105.	123.
	Te x-ray	210Pb	234Th	155Eu	234Th	155Eu	155Eu
CLV-1,	1.032 ± 0.007	1.034 ± 0.009	(1.029)*	1.020 ± 0.0009	(1.022)*	1.013 ± 0.014	1.015 ± 0.008
(71 g)							
CLV2	1.038 ± 0.007	1.044 ± 0.009	(1.029)*	1.019 ± 0.009	(1.022)*	1.018 ± 0.014	1.019 ± 0.004
(70 g)							

* interpolated value

Table 7 - Results of gamma-ray measurements of isotope activities in CLV-1, and CLV-2 71.0 g and 70.0 g samples respectively

Material	Isotope	Activity, Bq/g		$1\sigma^1$	S.D. ²	mean $\pm$ 95% CI ³
CLV-1	²³⁸ U	1.179	1.162	1.147	0.016	1.162 $\pm$ 0.021
	²²⁶ Ra	0.687	0.689	(0.631) ⁴	0.004	0.687 $\pm$ 0.006 ⁴
	²¹⁰ Pb	0.667	0.765	0.683	0.026	0.690 $\pm$ 0.083
	¹³⁷ Cs	0.111	0.113	0.107	0.004	0.111 $\pm$ 0.004
CLV-2	²³⁸ U	0.0477	0.0450	0.0400	0.0053	0.0444 $\pm$ 0.0051
	²²⁶ Ra	0.0370	0.0394	0.0373	0.0015	0.0386 $\pm$ 0.0029
	²¹⁰ Pb	0.0773	0.0825	0.0841	0.0073	0.0808 $\pm$ 0.0049
	¹³⁷ Cs	0.0391	0.0353	0.0367	0.0018	0.0368 $\pm$ 0.0027

1. Estimated uncertainty due to counting statistics for individual determination.

2. Observed standard deviation of replicates from mean.

3. 95% confidence interval precision of mean; $t(S.D.)/\sqrt{n}$, where t = is Student's t for 3 degrees of freedom at the 5% significance level, i.e., 3.18.

4. Value rejected as physical outlier, due to probable ²²²Rn leakage.

Table 8 - ^{222}Rn emanation efficiency, %E, of CLV-1 and CLV-2, 70 g/125mL in steel can with open top, 72cm^2 .

	Retained $^{222}\text{Rn}^1$, Bq/g ($\pm 2\sigma$)	% E ² ($\pm 2\sigma$)
CLV-1	0.1827 ± 0.0042 , 0.1785 ± 0.0042	73.7 ± 0.5
CLV-2	0.0274 ± 0.0028 , 0.0264 ± 0.0028	30.3 ± 7.4

1. Duplicate measurements 1 and 5 d after removal from bottle.
2. $100(1 - ^{222}\text{Rn}/^{226}\text{Ra})$, with ^{226}Ra from Table 7.

Table 9 - Expected decay of $^{210}\text{Pb}^1$ and $^{137}\text{Cs}^2$ activities. A/Ao is the predicted activity after t years relative to that at April 1985.

t (y)	A/Ao			
	CLV-1		CLV-2	
	^{210}Pb	^{137}Cs	^{210}Pb	^{137}Cs
2	0.956	0.955	0.960	0.960
5	0.894	0.891	0.904	0.891
10	0.803	0.793	0.822	0.793

1. $A/Ao = \exp(-\lambda t) + (1 - x) (A_{\text{Ra}}/Ao) (1 - \exp(-\lambda t))$, where $\lambda = 0.0311 \text{ y}^{-1}$, and Ao and A_{Ra} are the measured ^{210}Pb and ^{226}Ra activities, respectively.
2. Half-life of 29.94y assumed.

FIGURE 1

TIME(L) = 86400
PSET(L) = 86400

CLV-1 SAMPLE A 71.0G

16.17 19 APR 85
UNIT# 2 DT= 0%
TAG NO. = 0

-4.0 KEV VFS=LOG(2↑20)

CRT=(09-40)

2042.2 KEV

CANBERRA

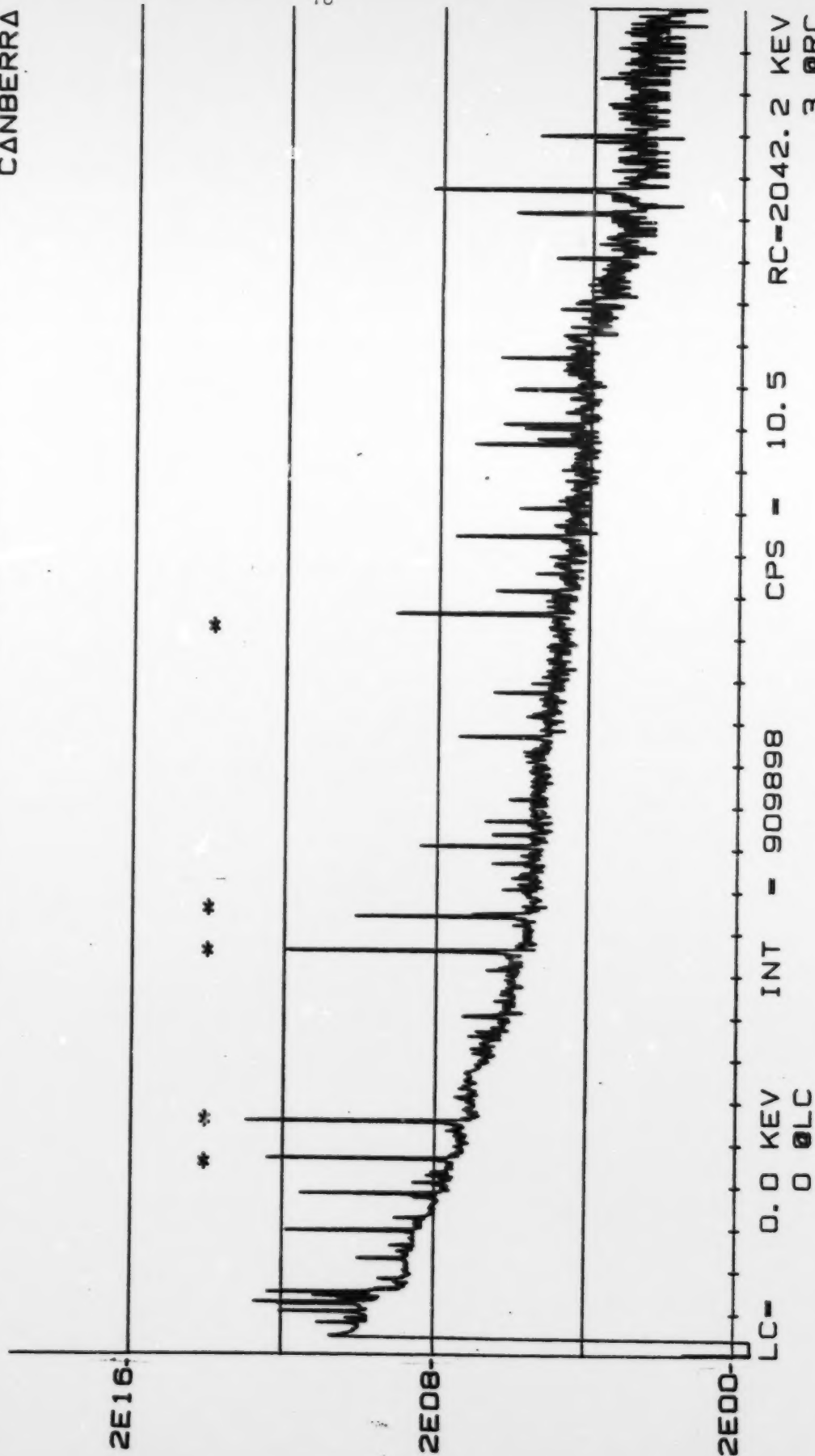


FIGURE 2

TIME(L) = 86400 CLV-2 SAMPLE A, 70.00G 14:46 15 MAR 85
PSET(L) = 86400 TAG NO. = 0 UNIT# 2 DT= 0%
-4.0 KEV VFS=LOG(2T20) CRT=(09-40) 2042.2 KEV
CANBERRA

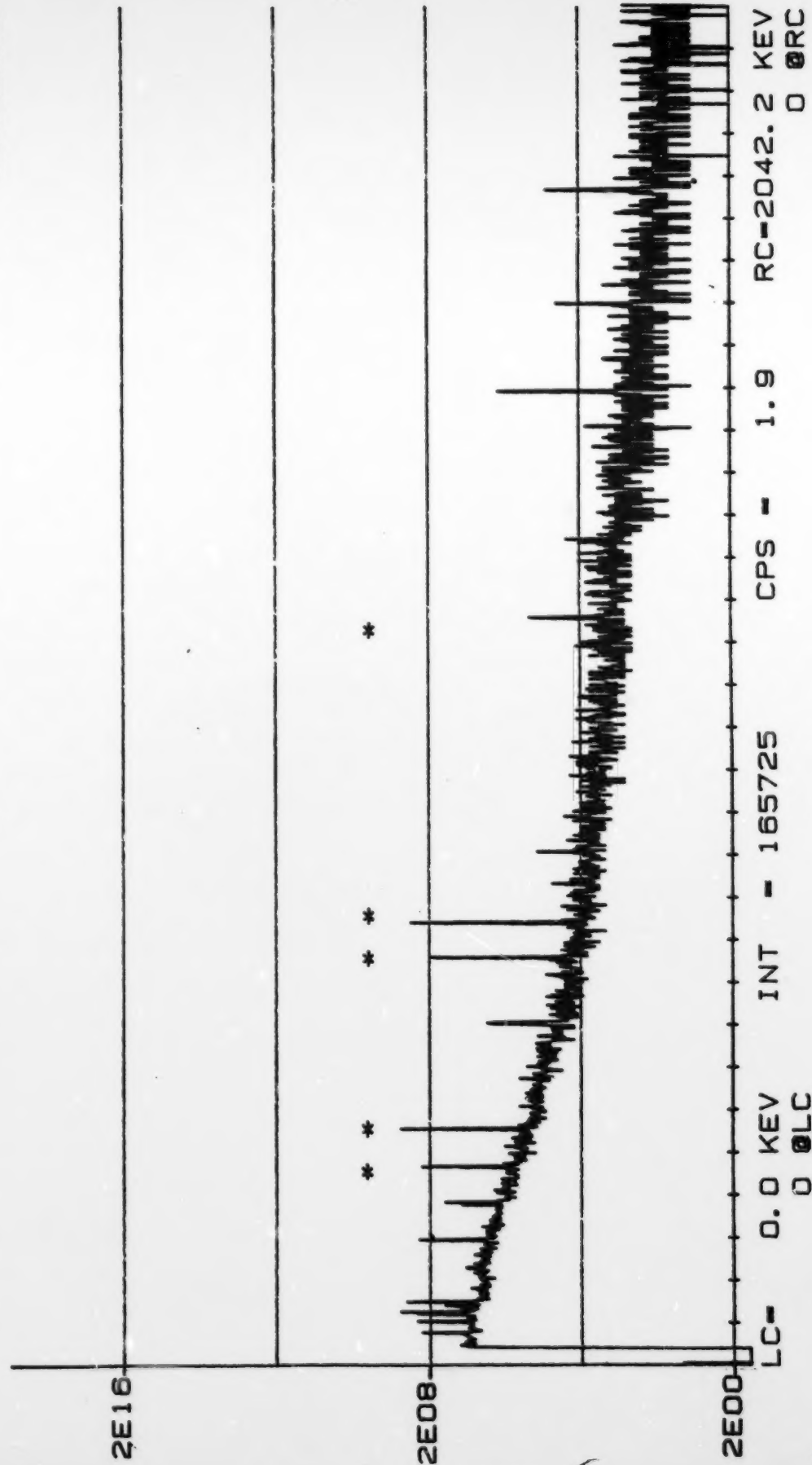


FIGURE 3

TIME(L) = 86400
PSET(L) = 86400

LI2B407 POWDER; 70.00G

10:47 6 MAR 85
UNIT# 2 DT= 1%
TAG NO. = 0
2042.2 KEV
CANBERRA

-4.0 KEV VFS=LOG(2120) CRT=(09-40)

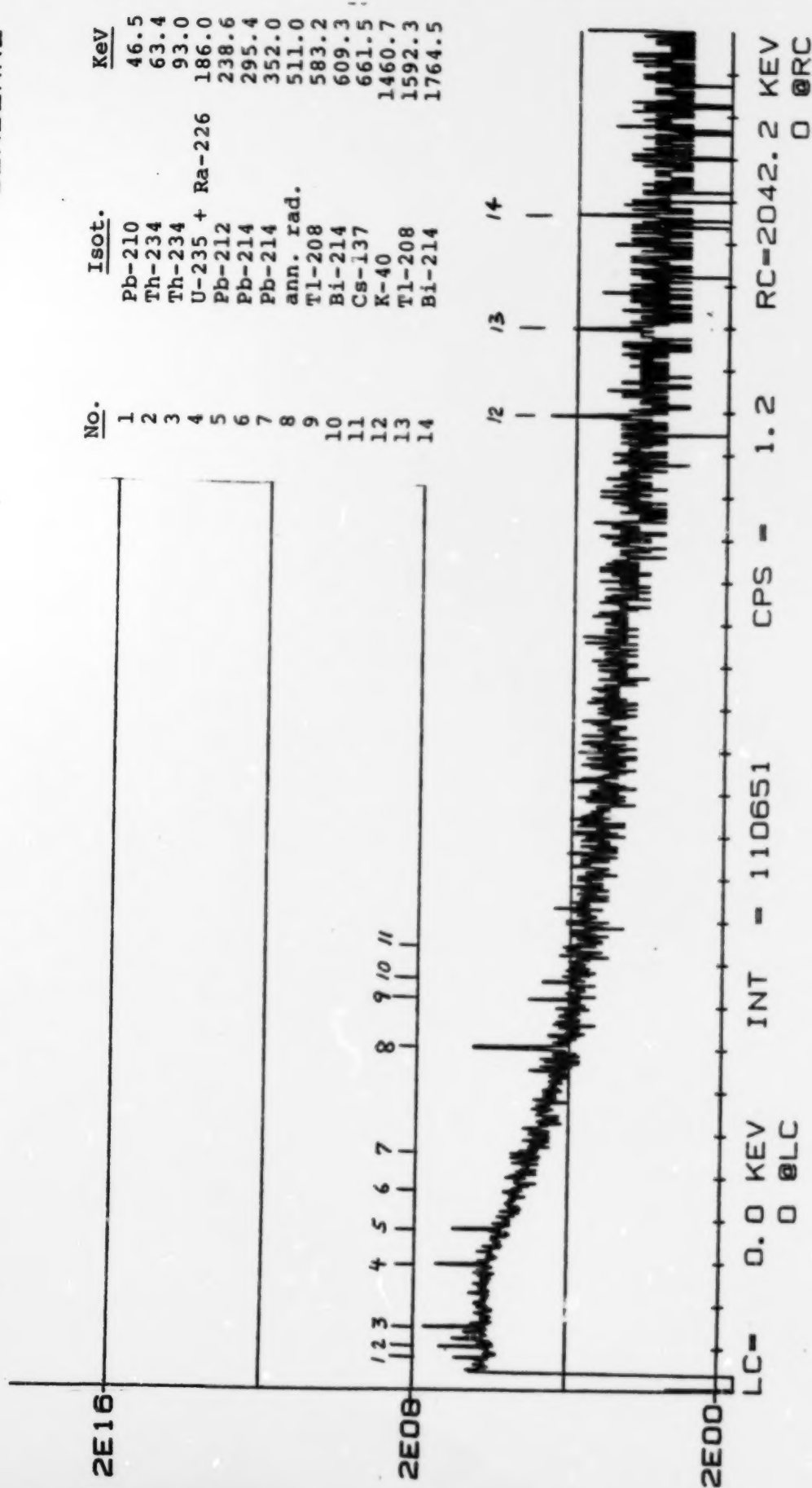


FIGURE 4

TIME(L) = 86512 CLV-1 SAMPLE A. 71.0G 09.31 23 APR 85
 PSET(L) = 86400 TAG NO. = 0
 43.50 KEV VFS = 2048 CRT = (41-56) 96.66 KEV
 CANBERRA

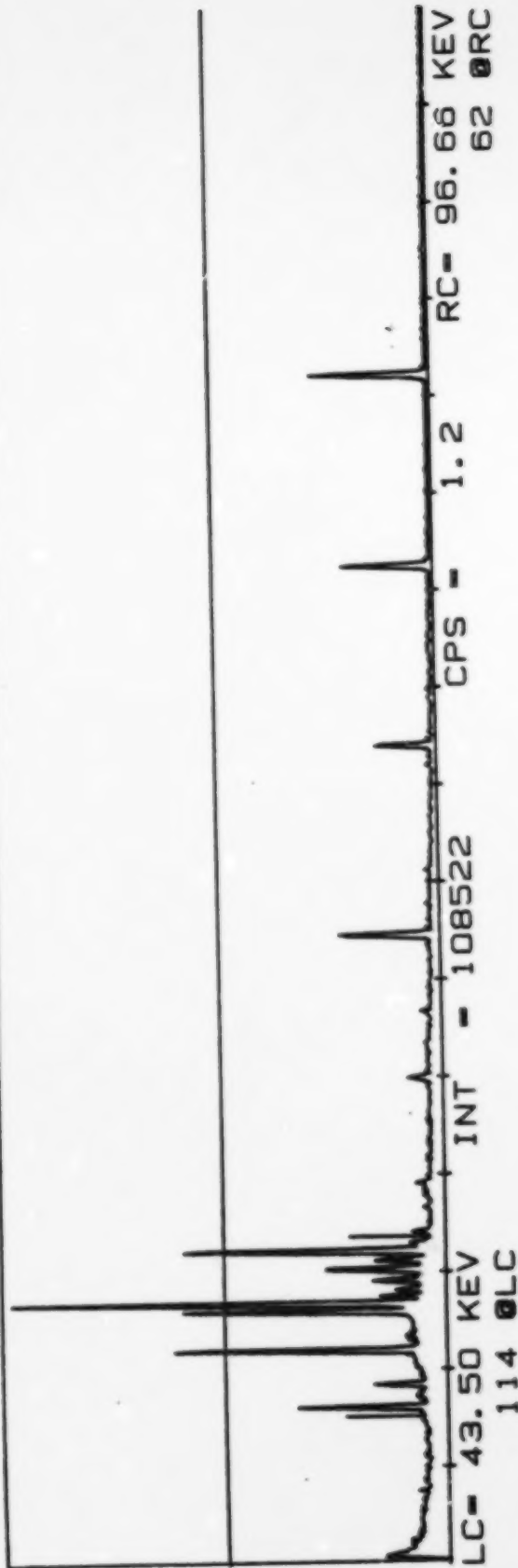
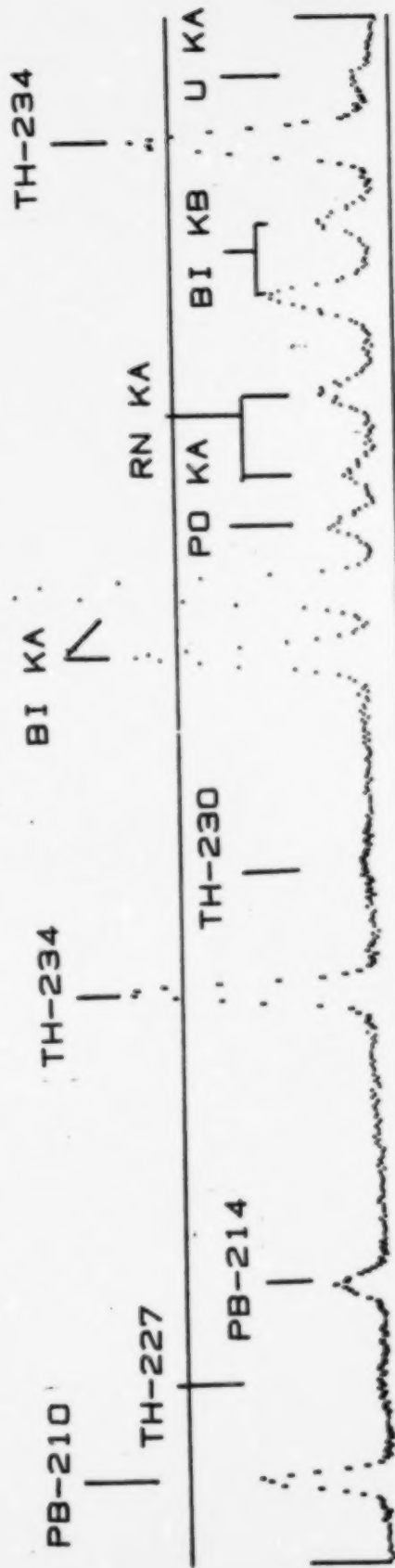
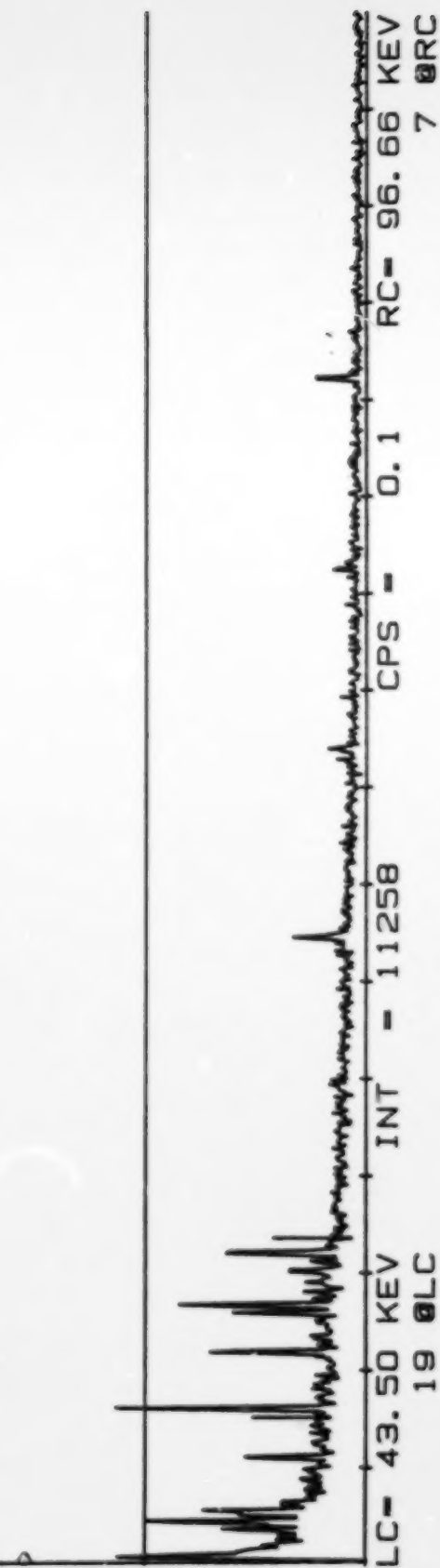
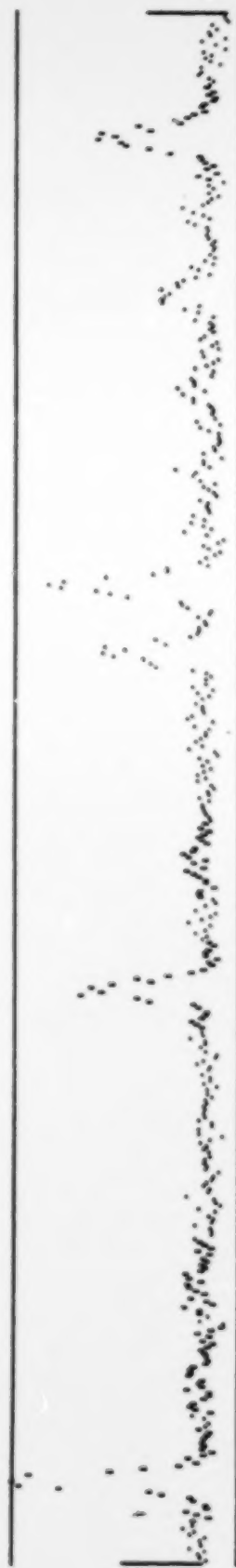


FIGURE 5

TIME(L) = 86400	CLV-2 SAMPLE A, MYL WIN.	13:04	26 APR 85
PSET(L) = 86400		UNIT# 3	DT = 0X
		TAG NO. =	0
43.50 KEV	VFS = 256	CRT = (41-56)	96.66 KEV
			CANBERRA



APPENDIX

CERTIFICATES OF CALIBRATION REFERENCE MATERIALS.

Description Principal radionuclides: Lead-210 Product code: RBZ.44
 Daughter radionuclides: Bismuth-210
 + Polonium-210 Solution number: 50/8/54

Measurement Reference time: 1200 GMT on 1 May 1980
 Radioactive concentration of lead-210: 0.958 microcuries per gram of solution
 which is equivalent to: 35.4 kilobecquerels per gram of solution
 Mass of solution: 5.3303 grams
 Total activity of lead-210: 5.10 microcuries
 which is equivalent to: 189 kilobecquerels
 Method of measurement:
 The solution was standardized by repeated 4 pi alpha counting over a period of 82 days.

Accuracy Overall uncertainty in the radioactive concentration quoted above: $\pm 2.4 \%$
 Random uncertainty: $\pm 0.6 \%$ Systematic uncertainty: $\pm 1.8 \%$
 Overall uncertainty is defined on the reverse of the certificate.

Radionuclidic Purity The estimated activities of any radioactive impurities found by high resolution gamma ray spectrometry, or in any other examination of the solution, are listed below expressed as percentages of the activity of the principal radionuclide at the reference time:
 Other radionuclides less than 0.01 %

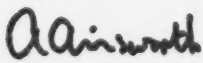
Chemical Composition 2M HNO₃ containing 100 micrograms of lead and 100 micrograms of bismuth per ml.

Physical Data Recommended half-life: 22.3 $\pm$ 0.2 years
 Lead-210: 100% beta particle emission.
 Bismuth-210: 100% beta particle emission. Half-life 5.01 $\pm$ 0.01 days
 Polonium-210: 100% alpha particle emission. Half-life 138.38 $\pm$ 0.01 days

Remarks The ratio of the activity of of bismuth-210 to the activity of lead-210 = 1.0006
 The ratio of the activity of of polonium-210 to the activity of lead-210 = 0.9559 at the reference time and will slowly increase to a theoretical maximum of 1.0179
 Tests made over 4 years on standardized solutions of lead-210 stored in glass ampoules have shown that loss of lead-210 from solution is negligible other than by radioactive decay. There is no guarantee that all the polonium-210 will remain in solution.

Approved


 Physics Department


 for Managing Director



Certificate of measurement of sources containing radium-226

Description

1-Radium Salt Capillary Type RA 31

Half-life 1600 years

Dimensions:

External length

mm

External diameter

3 mm

Active length

mm

Screenage

0.5 mm

of

GLASS

- mm

of

-

Measurement

On

21 June 1977

the content of radium-226 was

Source number	Content (micro grams)
31549	112.9

Source number	Content (grams)

AccuracyThe OVERALL UNCERTAINTY in the quoted content of each source is estimated to be less than $\pm 5\%$

This estimate of uncertainty is calculated in accordance with the recommendations of the International Commission on Radiation Units and Measurements (ICRU Report 12). The limits of uncertainty are taken as the arithmetic sum of the uncertainty due to random variations, calculated at the 99.7% confidence level, and the estimated maximum uncertainties due to systematic errors. The systematic uncertainties include the estimated overall uncertainty in the content of the standard source used for the comparison.

Notes

1. Tests for leakage of radon-222 have been carried out with satisfactory results.
2. The radionuclide in these sources is radium-226 in equilibrium with its immediate decay products. It may contain traces of thorium-228 and actinium-227. At the reference time the activity of either impurity was less than 0.1% of the activity of the radium-226. The resulting uncertainty in the measurement of the radium-226 content has been included in the assessment of accuracy.
3. The measurement was made by comparing the rate at which gamma radiation emerged from the source with that from a standard radium-226 source, using ~~an end-window type gas flow proportional counter~~ sodium iodide detector.
4. ~~The estimated maximum uncertainty in the measurement of the radium-226 content has been included in the assessment of accuracy.~~
5. ~~The estimated maximum uncertainty in the measurement of the radium-226 content has been included in the assessment of accuracy.~~

Lab. ref. CMR 6168

Approved

Cole
Radiation Sources department

E. H. H.
Physics department

G. L. Harris
for Managing Director